AIR QUALITY FORT FRANCES

Annual Report, 1977

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of the
Environment

AIR QUALITY

FORT FRANCES

Annual Report, 1977

TECHNICAL SUPPORT SECTION
NORTHWESTERN REGION
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CONTENTS

SUMMARY

The Ontario Ministry of the Environment has conducted air quality assessment investigations in Fort Frances since 1972. This report presents results of the 1977 programme, which included vegetation studies, snow sampling, and air quality monitoring in the vicinity to two local kraft pulp mills on the Ontario-Minnesota border.

Vegetation injury attributed to kraft mill emissions extended over a slightly larger area in 1977 than in 1976, but was less extensive than that recorded in 1974 or 1975. Sodium and chloride levels in tree foliage near the Fort Frances mill were also a little higher in 1977 than in the preceding year. Elevated concentrations of calcium, chloride and sodium were also found in moss experimentally exposed in the same area.

Meltwater from snow collected in February contained excessive amounts of sodium and sulphate, particularly in the vicinity of the Canadian mill. Sawdust was often observed in snow for some distance from the mill area.

High dustfall levels, well above the Ontario air quality objective, were regularly encountered near the Fort Frances mill. As in 1976, sawdust and sulphate were significant components of total dustfall. Concentrations of total suspended particulate periodically exceeded the Ontario daily objective in the same area.

Sulphation rate measurements and continuous monitoring showed that excessive concentrations of total reduced sulphur (TRS) frequently occurred near the Fort Frances mill. Levels of TRS were as much as 18 times the Ontario air quality objective, and were above the objective for more than 1100 hours at the two monitoring sites during the year. Wind direction analysis established that the pulp mills were the principal sources of TRS emissions.

Results of investigations in 1977 indicated that air quality in the vicinity of the kraft pulp mill in Fort Frances was highly unsatisfactory. Levels of particulate and gaseous pollutants were well above Ontario regulations and there was little evidence of improvement over past years.

INTRODUCTION

In 1972, the Ontario Ministry of the Environment began air quality assessment investigations in Fort Frances in response to complaints from local residents concerning alleged adverse effects of atmospheric emissions from a new 500 ton-per-day bleached kraft pulp mill. Results of studies from 1972 to 1976 (1, 2) established that environmental damage had occurred following the discharge of gaseous and particulate contaminants from this mill and from a similar plant located nearby in International Falls, Minnesota.

The 1976 assessment programme was continued in 1977 with little change, and included vegetation assessment studies, a snow sampling survey, and air quality monitoring.

VEGETATION ASSESSMENT

VEGETATION INJURY

Because of its widespread local occurrence and its apparent sensitivity to injury, Manitoba maple (*Acer negundo*) was selected in 1973 as an indicator species in assessing the degree and extent of vegetation damage from air pollutants in Fort Frances and International Falls. Judged from visible injury to Manitoba maple foliage, the 1977 "injury zone" was about 12 ha (hectares) in area (Figure 1), compared with about 8 ha in 1976, 20 ha in 1975 and 26 ha in 1974. All injury was attributed to emissions from the Canadian mill. Most of the severe vegetation damage was confined to an area of former residential properties which were recently acquired by the mill to establish a "buffer zone" along a portion of Nelson Street and Portage Avenue. The sole complaint of vegetation injury during the 1977 growing season was submitted by a resident adjacent to the "buffer zone". The continued

absence of vegetation damage near the U. S. mill was attributed to significantly reduced emissions following the installation of a new recovery furnace in that plant in 1976.

In the vicinity of the Fort Frances mill, air pollution injury was noted on foliage of a variety of shade trees, shrubs, garden flowers and vegetable crops. Symptoms varied widely among plants affected, but necrosis (death) of leaf tissue was commonly observed. Repeated injury over several years has resulted in dieback, and sometimes death, of a number of shrubs and trees. Effects due to insects or disease could normally be distinguished without difficulty from those ascribed to atmospheric pollutants.

CHEMICAL ANALYSIS

Triplicate samples of Manitoba maple foliage were collected in August from the same 26 sites sampled in 1975 and 1976 (Figure 2). The two control locations were situated on the outskirts of Fort Frances, about 4 km (kilometres) from both pulp mills. Each sample, about 500 g (grams) fresh weight, was obtained by manually trimming outside leaf growth to a height of 6 m (metres) above ground on the sides of trees facing the source. Trees at sites 12 to 16, inclusive, were also sampled on the side away from the source. Foliage was placed in perforated polyethylene bags and stored under refrigeration ($4^{o}C$) until processed in the Ministry's laboratory facilities in Thunder Bay. Sample material was dried in an oven at $80^{o}C$ for 30 hours, then ground in a Wiley mill equipped with a 1-mm (millimetre) pore-size screen. The powdered vegetation was submitted for chloride and sodium analysis at the Ministry's Toronto laboratory. Chloride was determined by a colorimetric technique, and sodium was analysed by atomic absorption spectrophotometry following ashing and acid digestion.

The chemical analysis data are summarized in Table 1, together with comparable values for earlier years. At sites closest to the Fort Frances mill, sodium levels were higher in 1977 than in 1976. Otherwise, there was little significant difference between results for the two years. Two values (at sites 1 and 12) exceeded the current Ontario guideline of 600 µg/g (micrograms per gram) for sodium in vegetation. Sodium in Manitoba maple at locations under the potential influence of the U. S. mill (sites 19 to 32) were well below the guideline, reflecting the benefit of pollution controls installed in this mill in 1976. The data are plotted in Figure 3. Though sodium concentrations decreased with increasing distance from the Fort Frances mill, the distribution pattern for sodium differed from that for visible injury.

Chloride levels in Manitoba maple samples in 1977 were also a little higher than in those for 1977 at sites near the Canadian mill. Values declined with increasing distance from the source. Chloride in maple foliage from points near the International Falls mill was satisfactorily low.

Data from foliage facing and away from the Fort Frances mill are compared in Table 2. For sodium (a particulate pollutant), there was a significant difference between "facing" and "away" values close to the source. For chloride (emitted as a gaseous contaminant), this difference was not apparent. These findings provide further evidence that elevated sodium in vegetation arises from the deposition of sodium-containing pollutant(s) discharged from the pulp mill.

The specific causes of vegetation damage near the Fort Frances mill have not been defined. Emissions of chlorine and black liquor have been linked to episodes of severe injury in the past, but both of these contaminants have usually been associated with upset situations in the mill, rather than "normal" operating

conditions. Sodium analysis of vegetation is a useful indicator of the distribution of sodium contamination, but the latter is not thought to be the primary cause of observed injury (3). Published evidence (4, 5) suggests that hydrogen sulphide may cause visible injury to plants. Since substantial concentrations of hydrogen sulphide and other organic sulphides have been monitored in the area where vegetation injury occurs in Fort Frances, experiments are being undertaken to determine the phytotoxicity of hydrogen sulphide to plant species common to the Fort Frances area.

MOSS BAG EXPOSURE

Mosses are effective substrates for absorbing and retaining some types of atmospheric pollutants by a passive ion-exchange process (6, 7). In Fort Frances, bags of *Sphagnum* moss were exposed from August 2 to September 6 at 34 sites (Figure 4). All but two sites were the same as those selected in 1976. Controls were situated about 4 km from the pulp mills. Each sample comprised about 4 g of oven-dried moss contained in a 10- by 20-cm (centimetre) envelope of fibreglass screening attached with Velcro strips to a supporting structure about 2.5 m above ground level. Samples, after exposure, were placed in polyethylene bags for refrigerated storage (at $4^{o}C$) until processed in the Ministry's Thunder Bay laboratory. The moss was dried at $80^{o}C$ for 30 hours, then ground in a Wiley mill equipped with a 1-mm pore-size screen. At the Ministry's Toronto laboratory, chloride was determined colorimetrically, and calcium and sodium were analysed by atomic absorption spectrophotometry after the moss was ashed at high temperature.

The moss bag analytical data are plotted in Figures 5-7. Concentrations of all three contaminants were highest near the Fort Frances mill and declined with increasing distance from this

area. Both calcium and chloride levels were similar to those for moss exposed in 1976. Sodium results for 1977 were more indicative of a source of airborne contamination than they were in 1976, possibly because of greater care in handling the moss before and after the 1977 exposure experiment.

SNOW SAMPLING

Snow sampling is often useful in assessing the kind, amount and extent of particulate pollutants near industrial sources of air pollution. Guidelines have been developed for concentrations of several elements in snow meltwater. Values exceeding the guidelines do not necessarily imply adverse environmental effects, but indicate that contaminants occur at concentrations significantly above those in unpolluted snow.

Snow was collected in February from the same 31 sites sampled in December, 1975 (Figure 8). Two sampling methods were employed: one in which snow was obtained from a surface area of 50 by 50 cm and a fixed depth of 20 cm, and a second method in which a core of the complete snow profile was collected. Sampling devices for both methods were plastic and free of metallic parts. Snow samples were transferred to clean, heavy-gauge polyethylene bags and retained in unmelted condition until ready for processing. Total depth of snow, depth of fresh snow and the presence of visible surface and subsurface contaminants was recorded. Just prior to melting, sample material was transferred to new polyethylene bags in the laboratory to avoid danger of contamination from bag leakage. The latter were placed in clean, plastic pails and melting then proceeded at indoor temperatures. After meltwater was obtained (usually 12 to 18 hours), pH was determined. Meltwater was vigorously stirred to ensure uniform distribution of particulate matter, then poured into clean, 1-litre plastic bottles. Calcium was determined by EDTA titration, carbon by automatic carbon analyzer,

chloride by silver nitrate titration, sodium by flame photometry, and sulphate by colorimetric titration with methyl thymol blue.

Results from the snow survey are presented in Table 3 and in Figures 9 and 10. Values for fixed depth and core sampling were similar and were therefore averaged to produce the results shown. The data clearly show the presence of elevated levels of all parameters near the Fort Frances mill, and a gradient of decreasing concentrations with increasing distance. Many values for sodium and sulphate were well above the contamination guideline of 10 mg/l (milligrams per litre). The calcium guideline (5 mg/l) was less frequently exceeded, and that for chloride (5 mg/l) was rarely exceeded. Concentrations in 1977 were much higher than those in 1975, when the mill was closed. In contrast, near the U. S. mill, 1977 values were significantly lower than those for 1975 because of reduced emissions from the new recovery furnace at the latter source. The presence of high carbon levels was attributed to the deposition of sawdust and other wood fines near the Fort Frances mill. Wood fines were noted in sample material at all sites near the Canadian mill but not around the International Falls plant. Visible particulate matter was recorded in snow up to about 500 m east, northeast and north of the Fort Frances mill. Some black particulate, probably bark char, was found at sites 6, 9, 10 and 29-32. About 12 cm of snow was considered as "fresh", having fallen within the 10-day period before sampling. Total depth of snow cover ranged from 24 to 56 cm and averaged 39 cm.

AIR MONITORING

PARTICULATE POLLUTANTS

Dustfall

Dustfall is one of the most visible kinds of air pollutants

and comprises particulate matter which settles out from the atmosphere by gravity. It is measured by exposing open-top plastic jars to the air for 30 days and weighing the collected matter. Specific components of dustfall may also be determined by chemical analysis or microscopic examination. Results are normally expressed in g/m^2 (grams per square metre) for 30 days. The Ontario air quality objectives for total dustfall are 7 g/m^2 for 30 days and 4.6 g/m^2, annual average. These values are equivalent to 20 and 13 tons per square mile which were, respectively, the monthly and annual objectives before conversion to metric units in January, 1977.

The 1977 monitoring sites are shown in Figure 4, with results summarized in Table 4. Very high dustfall levels were recorded near the Fort Frances mill. At sites closest to the mill, the monthly air quality objective was regularly exceeded. Annual averages declined with increasing distance from the plant area (Figure 12a), but the Ontario objective was met at only the two most distant monitoring stations. The data in Table 4 indicate that sulphate (probably as sodium sulphate) was an important component of dustfall, particularly at the location nearest the mill where it constituted about a quarter of total dustfall. Wood fines and, occasionally, bark char, were sometimes evident in dustfall jars in the Nelson Street/Portage Avenue/ Sinclair Street area. Re-entrainment of dust from movement of heavy vehicles and other equipment in the mill area probably also contributed to local dustfall levels. Though comparison of average dustfall levels for 1977 with those for 1975 or 1976 is complicated by a period of mill shutdown in late 1975 and early 1976, there is no evidence of any decrease in average dustfall loadings in the vicinity of the mill. There was no indication that operations at the U. S. mill contributed significantly to Fort Frances dustfall levels.

Suspended Particulate

Suspended particulate constitutes particulate matter of small size which remains in the atmosphere for extended periods. At scheduled intervals, usually every sixth day, a measured volume of air is drawn through pre-weighed glass fibre filters for a 24-hour period. Filters are re-weighed after exposure to determine the quantity of dust collected. Results are expressed in $\mu g/m^3$ (micrograms per cubic metre of air). The Ontario air quality objectives for suspended particulate are 120 $\mu g/m^3$ for a 24-hour average, and 60 $\mu g/m^3$ for the annual geometric mean.

Total suspended particulate (TSP) concentrations for 1977 at the two Fort Frances monitoring sites are given in Table 5. At station 62032, north of the U.S. pulp mill, the 24-hour objective was exceeded only once in 53 samples and the annual geometric mean of 32 $\mu g/m^3$ was well below the provincial objective of 60 $\mu g/m^3$. Although no extremely high TSP levels were encountered at station 62030, near the Fort Frances mill, eight values were over the 24-hour objective and the annual geometric mean, at 62 $\mu g/m^3$, was slightly above the Ontario objective. At this site, highest values (average 101 $\mu g/m^3$) were associated with southerly winds and lowest averages (average 66 $\mu g/m^3$) were monitored with west winds, indicating that the Fort Frances mill was an important source of fine particulate matter. Sawdust was visible on filters exposed on six dates in 1977 at station 62030.

GASEOUS POLLUTANTS

Sulphation Rates

Sulphation rates provide an indication of the presence of sulphur-containing gases in the air. They are determined by exposing small plastic dishes, coated with lead dioxide, to the atmosphere for 30-day periods. Lead dioxide combines with

reactive sulphur compounds to form lead sulphate. The quantity of sulphate formed is determined analytically and reported as mg SO_3/100 cm^2/day (milligrams of sulphur trioxide per hundred square centimetres per day). Although the method is usually applied to monitor average sulphur dioxide concentrations, measurable sulphation rates may also be obtained if other reactive gases are present. In Fort Frances, air quality surveys with mobile equipment have shown that sulphur dioxide levels are negligible (1). Therefore, hydrogen sulphide and other organic sulphides are considered to be the only reactive compounds contributing to local sulphation rates. The Ontario air quality objective of 0.70 mg SO_3/100 cm^2/day was established in relation to long-term average sulphur dioxide levels and is therefore not applicable to data from Fort Frances.

The 1977 sulphation rate data, for sites shown in Figure 11, are presented in Table 6. Averages were highest near the pulp mill and decreased with increasing distance (Figure 12b). Sulphation rates were somewhat higher in 1977 than in the two preceding years, but the temporary suspension of operations at the Fort Frances mill for a four-month period in late 1975 - early 1976 may have accounted for lower averages for those years.

Reduced Sulphur

A number of sulphur-containing gases are commonly emitted by kraft pulp mills. Hydrogen sulphide (H_2S) and methyl mercaptan (CH_3SH) are usually the principal components of this group of compounds. Other members of the group, normally considered to be minor components, are dimethyl sulphide ($(CH_3)_2S$) and dimethyl disulphide ($(CH_3)_2S_2$). These compounds are collectively referred to as "total reduced sulphur" (TRS) and all result in offensive odours at very low concentrations. At high levels, lead-based paints may be blackened, vegetation may be injured, and temporary

respiratory irritation may be experienced by persons in the area affected. A tentative guideline of 27 ppb (parts per billion, expressed as hydrogen sulphide, hourly average) has recently been established as the Ontario air quality objective for TRS in the vicinity of kraft pulp mills.

In 1977, TRS was continuously monitored at stations 62030 and 62032 with analysers that operated on the principle of coulometric titration (Philips model 9700 series). The analysers do not respond to the presence of potentially interfering pollutants, such as sulphur dioxide or hydrocarbons. Measurement ranges varied from about 0-200 to 0-800 ppb, depending on maximum TRS levels expected or encountered. The detection limit, on the most sensitive scale, was about 1 or 2 ppb.

Table 7 gives a summary of the 1977 TRS data. Some extremely high readings were obtained at station 62030 (Church Street and Portage Avenue), where 971 hourly averages (about 14 percent of the total) exceeded the air quality objective. Detectable concentrations were recorded 61 percent of the time, compared with 46 percent in 1976. The annual average was about 15 ppb, up from 13 ppb in 1976. Maximum hourly readings were similar in both years, 458 ppb in 1976 and 480 in 1977. Off-scale peaks were frequently recorded. August, October and November were the worst months with 148, 195 and 155 readings, respectively, above the 27 ppb guideline. In all three months, the monitor was downwind of the Fort Frances mill more frequently than normal. Figure 13 gives a graphical display of daily mean TRS levels at station 62030 and indicates the frequency with which concentrations exceed a theoretical 24-hour objective of 9 ppb.

Results for station 62032 (Fort Frances cemetery), though much better than those for the other site, were still not satisfactory. Of the 5128 hourly average values obtained in the

year, 176 (about 3 percent) were above the 27 ppb guideline. The maximum reading of 129 ppb was recorded in February. The difference in TRS levels between the two monitoring sites is well illustrated by comparing Figures 13 and 14.

The relationship between TRS readings and wind direction is summarized numerically in Table 8 and in the form of pollution roses in Figure 15. These data show that at station 62030, the bulk of the high concentrations were measured when the monitor was downwind of the Fort Frances mill. When downwind of the U.S. mill, concentrations were much lower (21 ppb average compared with 71 ppb). At station 62032, highest TRS levels (average 19 ppb) were associated with winds from the U.S. mill. When downwind of the Canadian mill, TRS concentrations averaged 11 ppb. At both stations, there were a number of low-concentration readings obtained when the wind was not from either pulp mill. The lagoon for liquid wastes from the Fort Frances mill has been identified as one of these minor sources of TRS. Sewage pumping stations in the town of Fort Frances are other possible sources now being investigated.

ACKNOWLEDGEMENT

The assistance of staff of the Ministry of Industry and Tourism in operating the TRS monitor at station 62030 is gratefully acknowledged.

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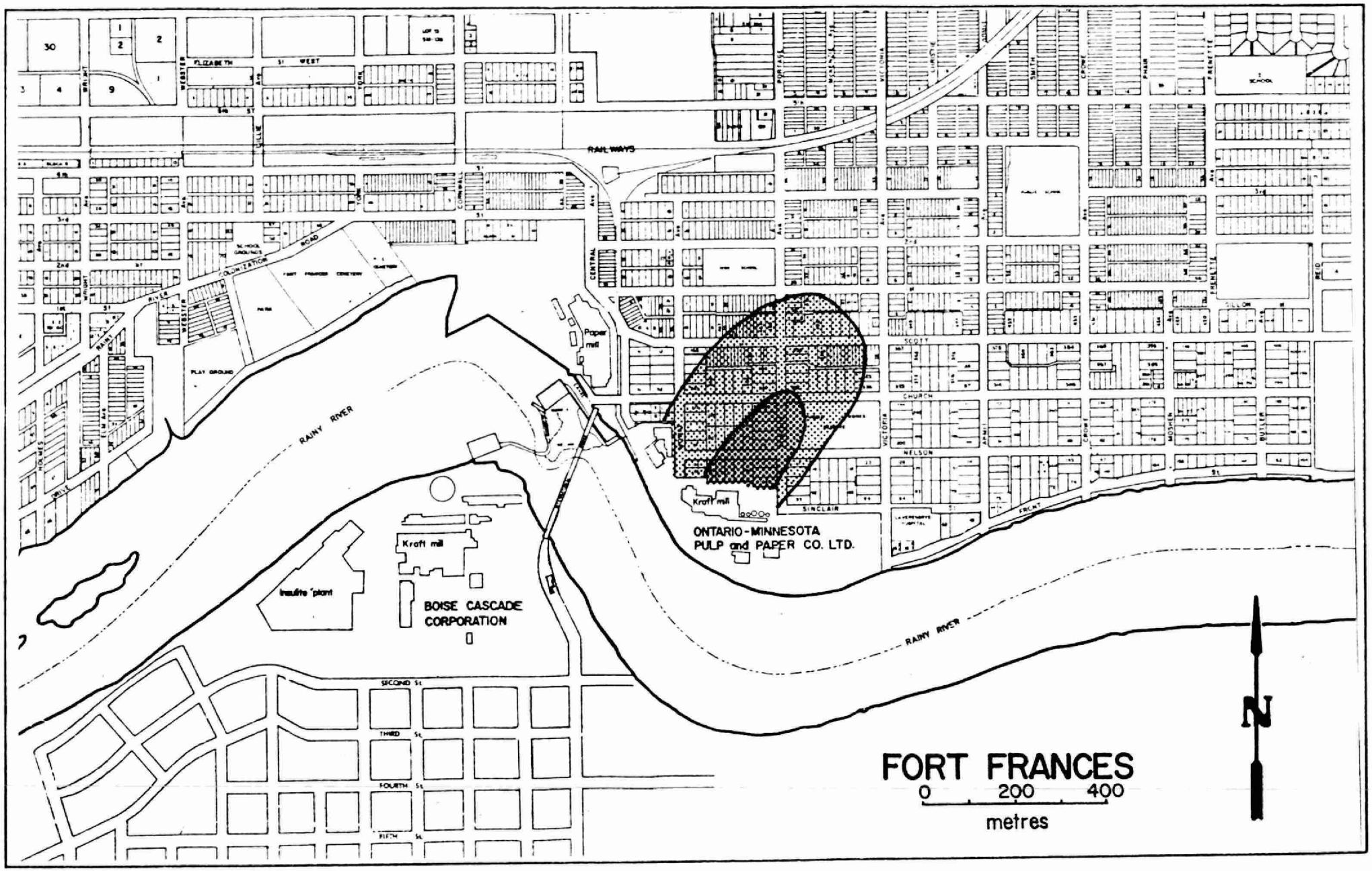

Figure I. Vegetation injury, August 1977.

Moderate to severe
Trace to moderate

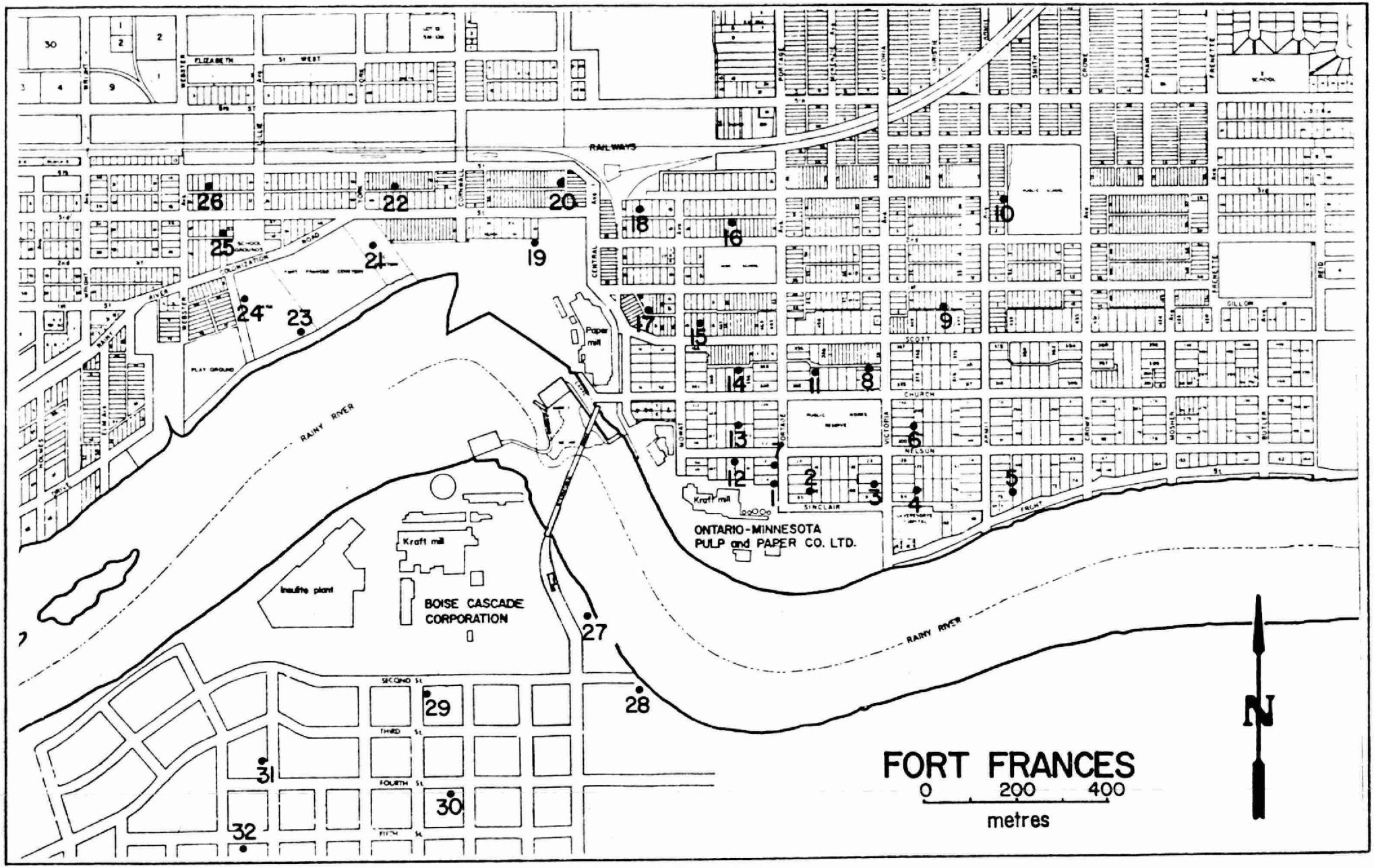

Figure 2. Manitoba maple sampling sites, 1977.

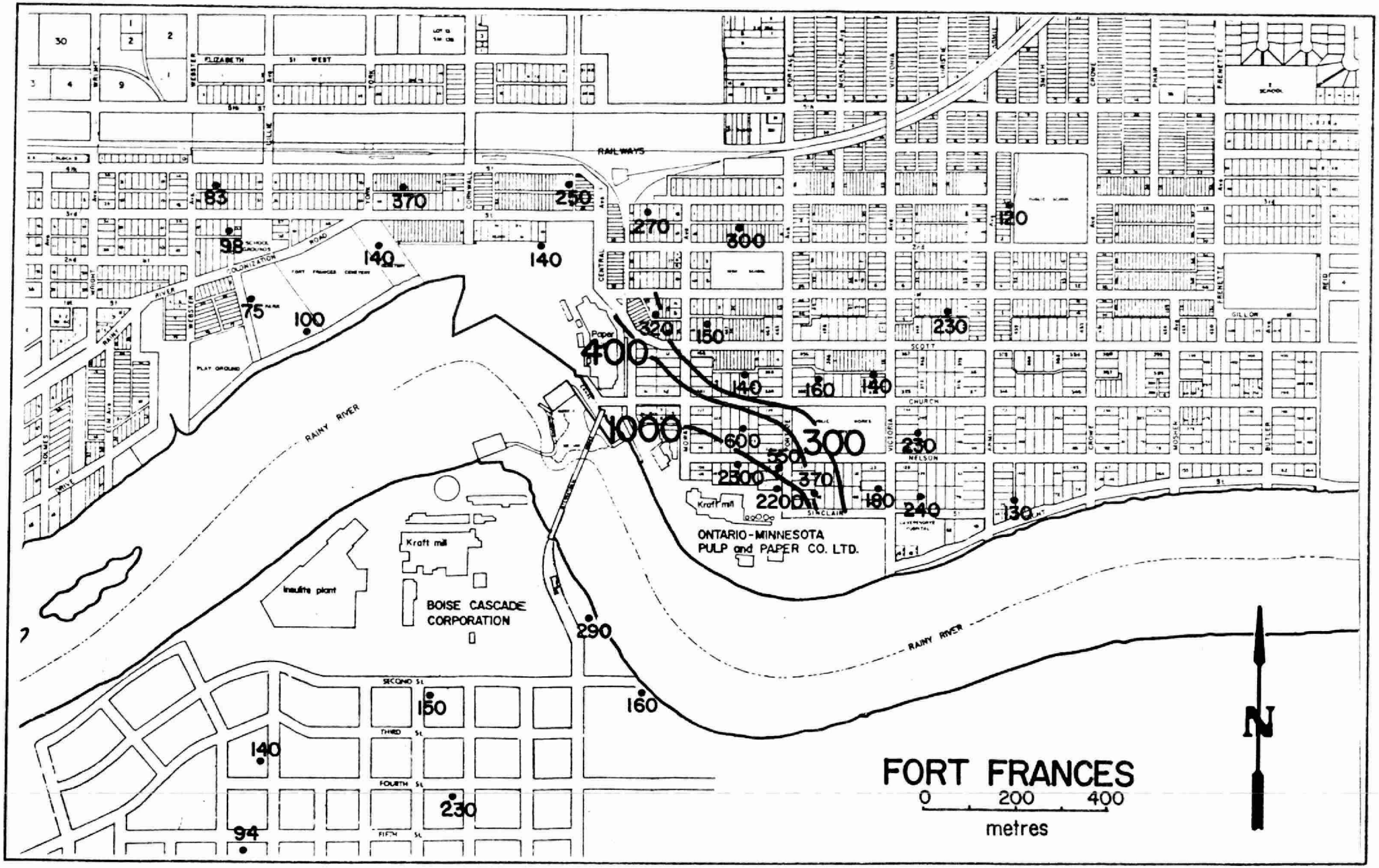

Figure 3. Sodium content (µg/g, dry weight) in Manitoba maple foliage, August, 1977.

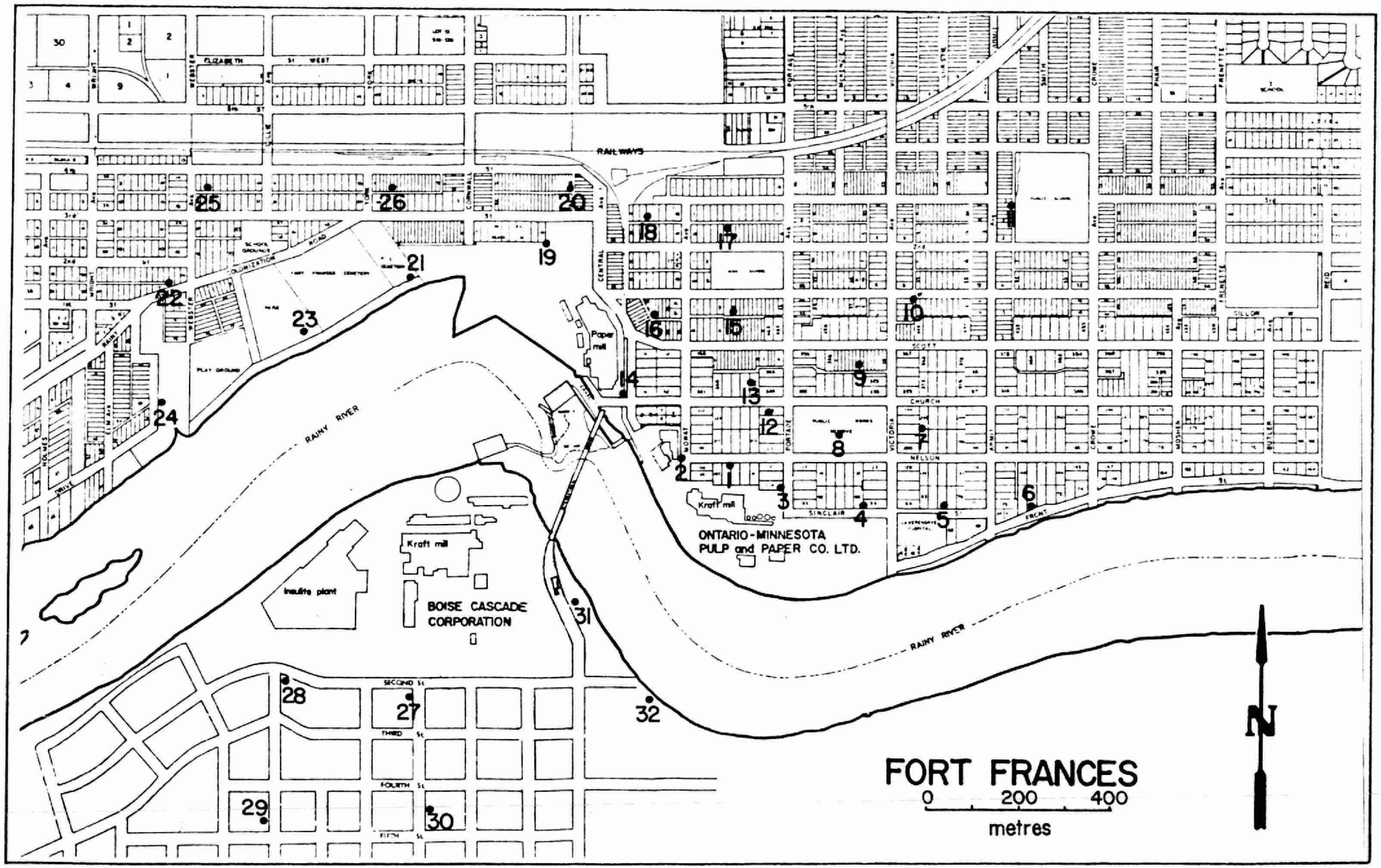

Figure 4. Moss bag exposure sites, 1977.

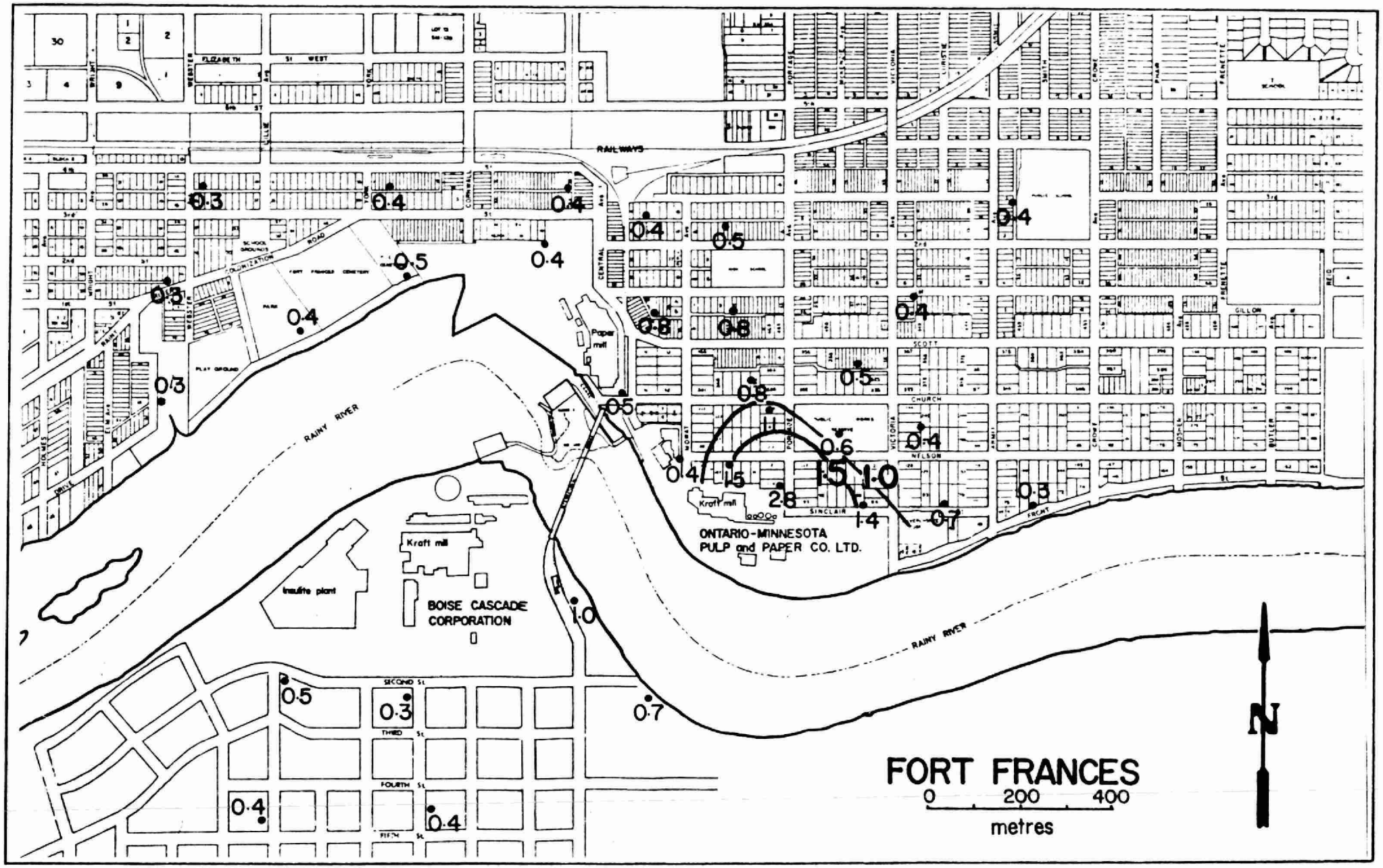

Figure 5. Calcium levels (µg/g, dry weight) in moss exposed August 2 to September 6, 1977.

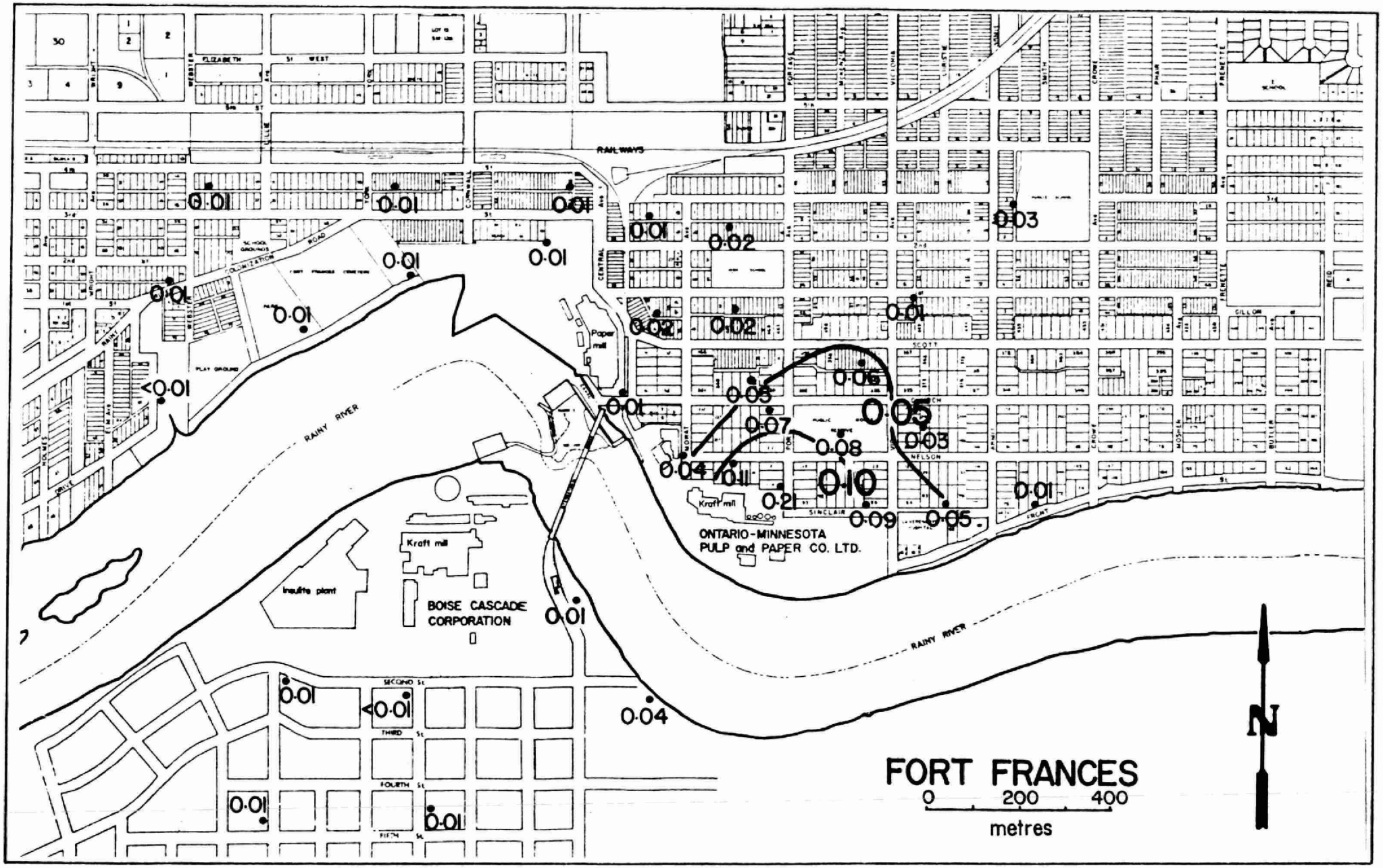

Figure 6. Chloride levels (%, dry weight) in moss exposed August 2 to September 6, 1977.

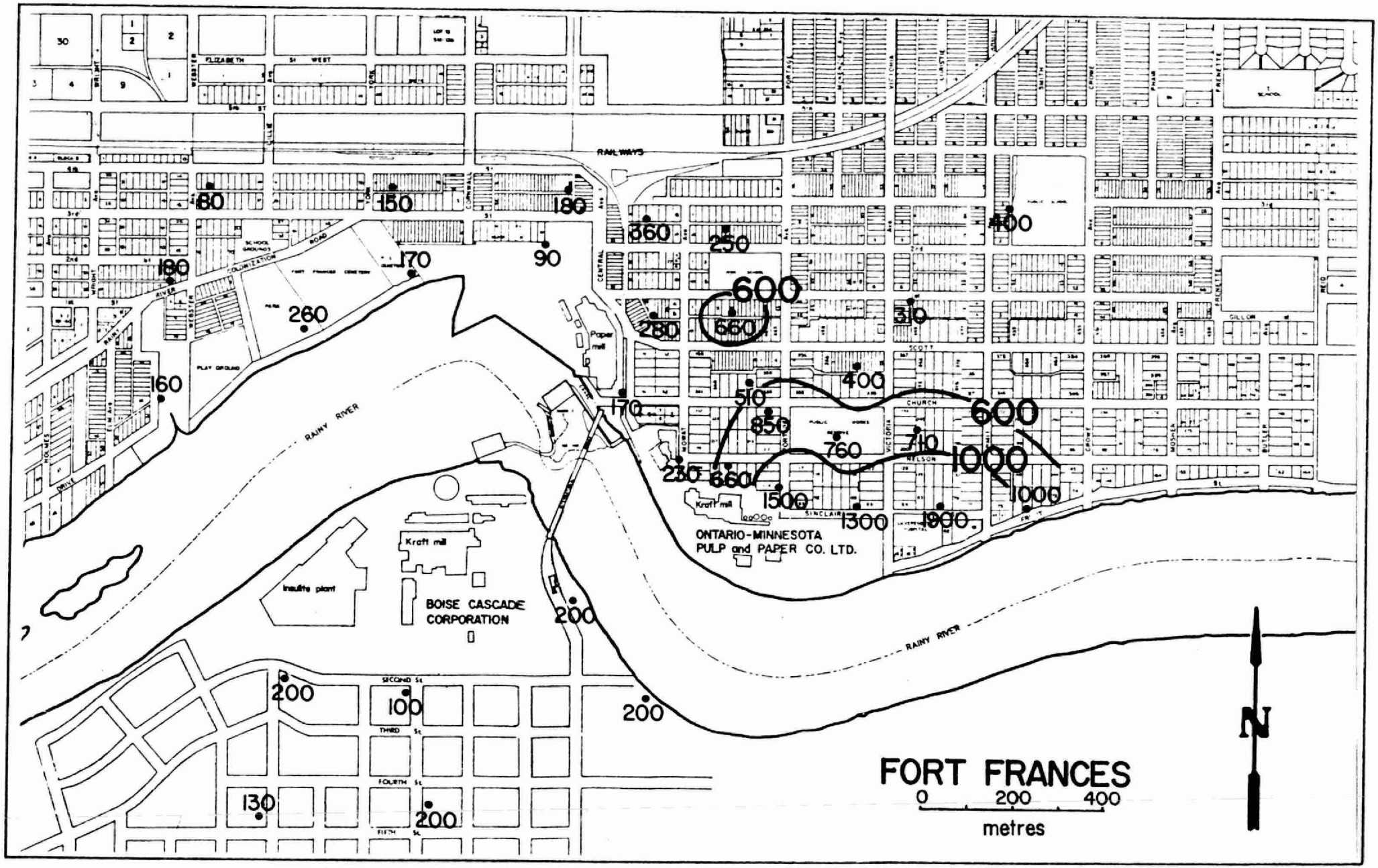

Figure 7. Sodium levels (µg/g, dry weight) in moss exposed August 2 to September 6, 1977.

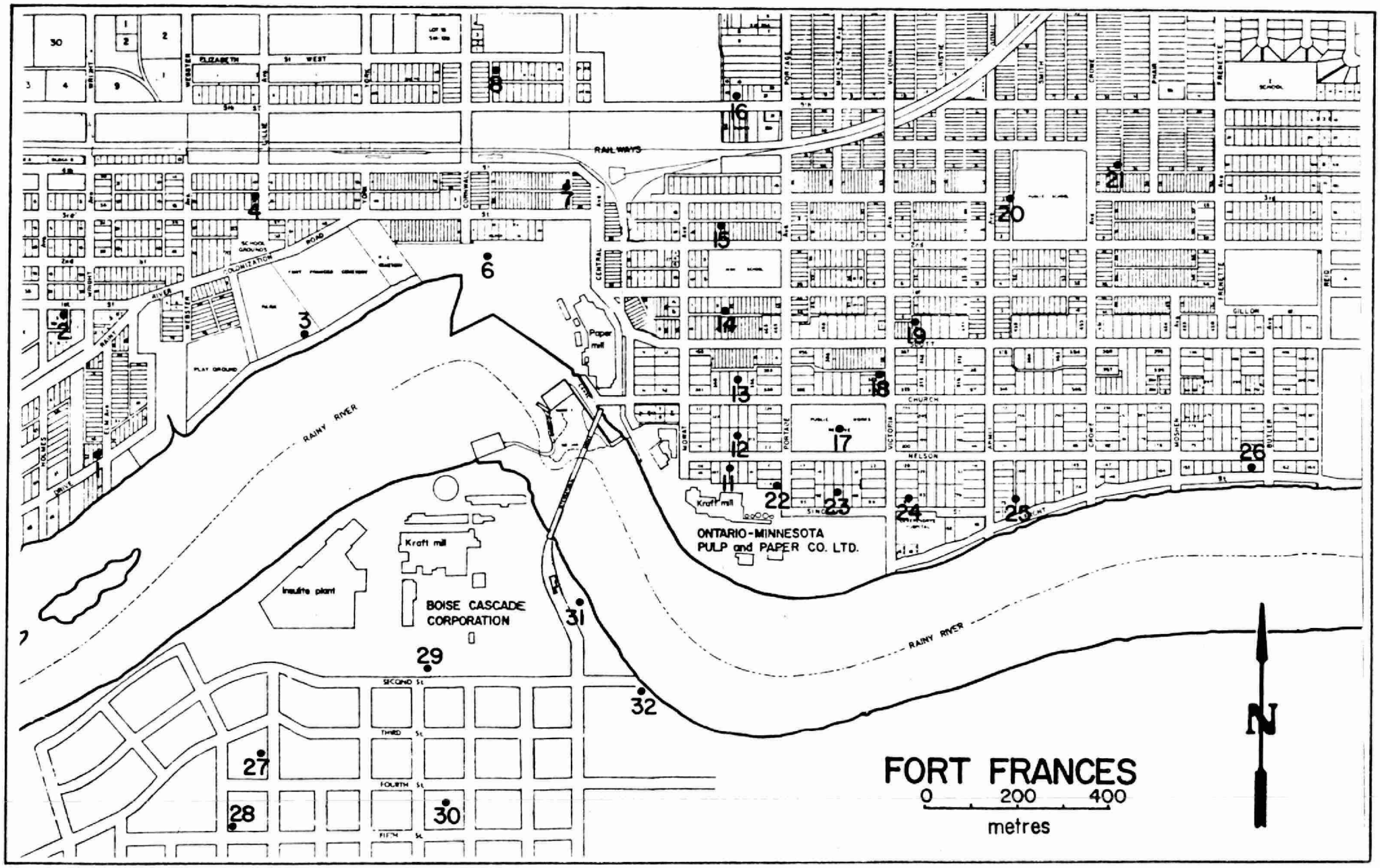

Figure 8. Snow sampling sites, 1977.

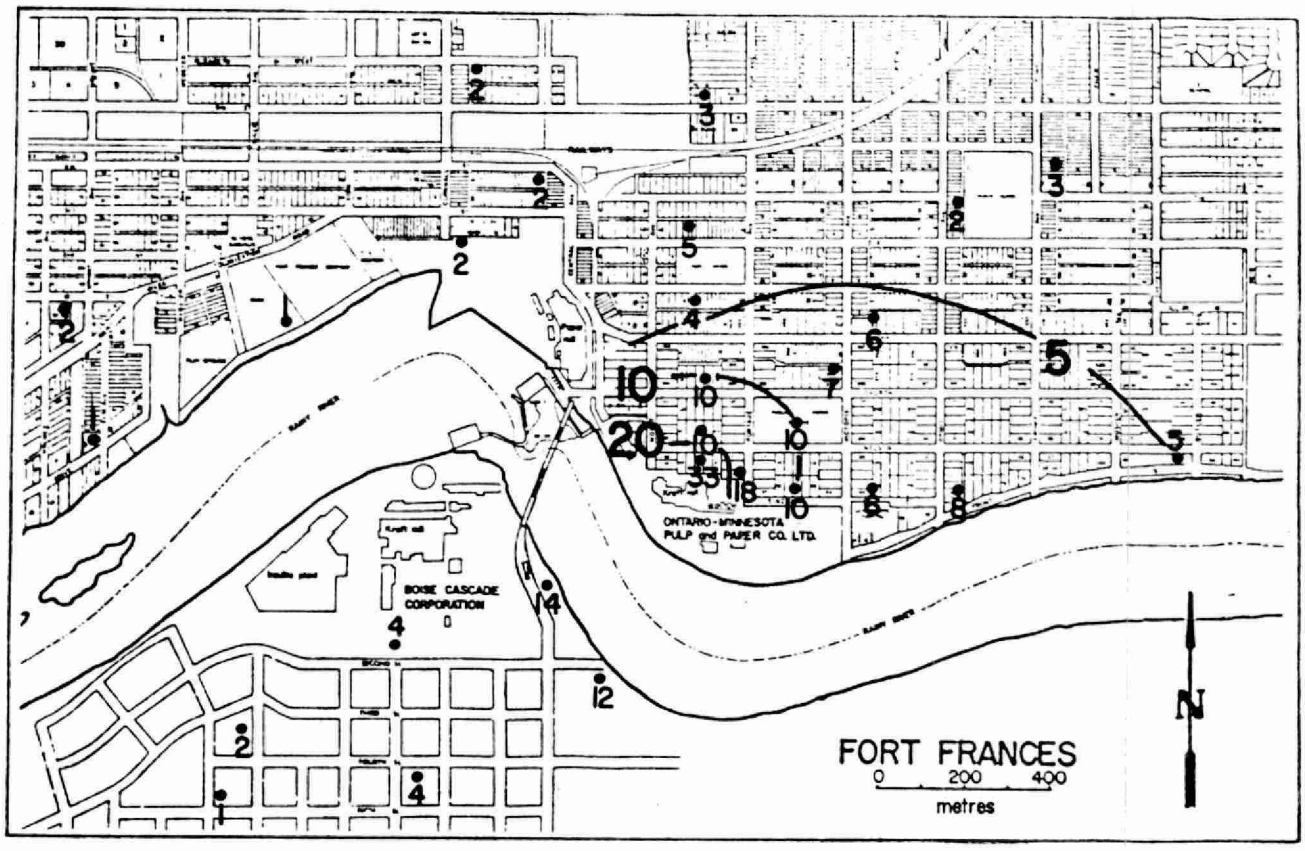

Figure 9a. Calcium levels (mg/l) in snow, February, 1977.

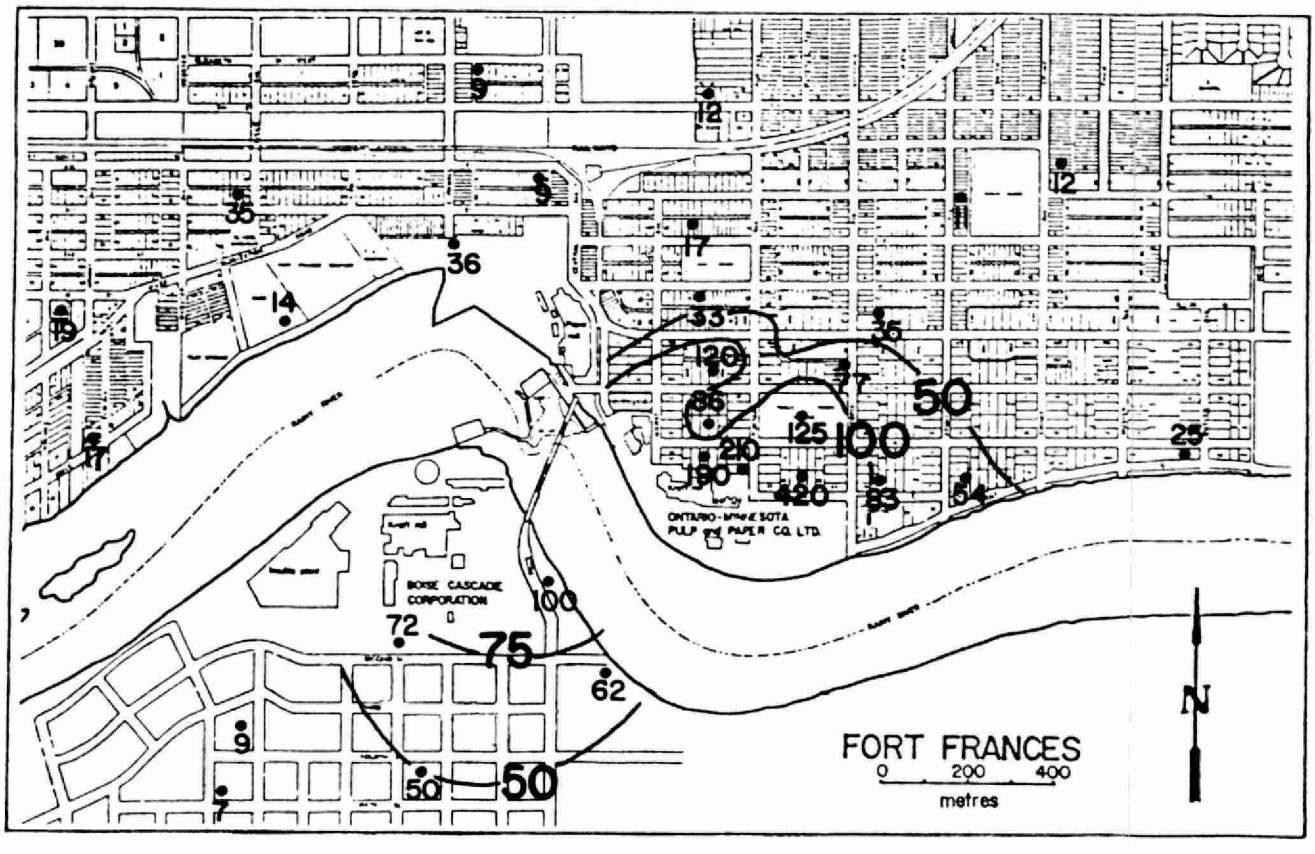

Figure 9b. Total carbon levels (mg/l) in snow, February, 1977.

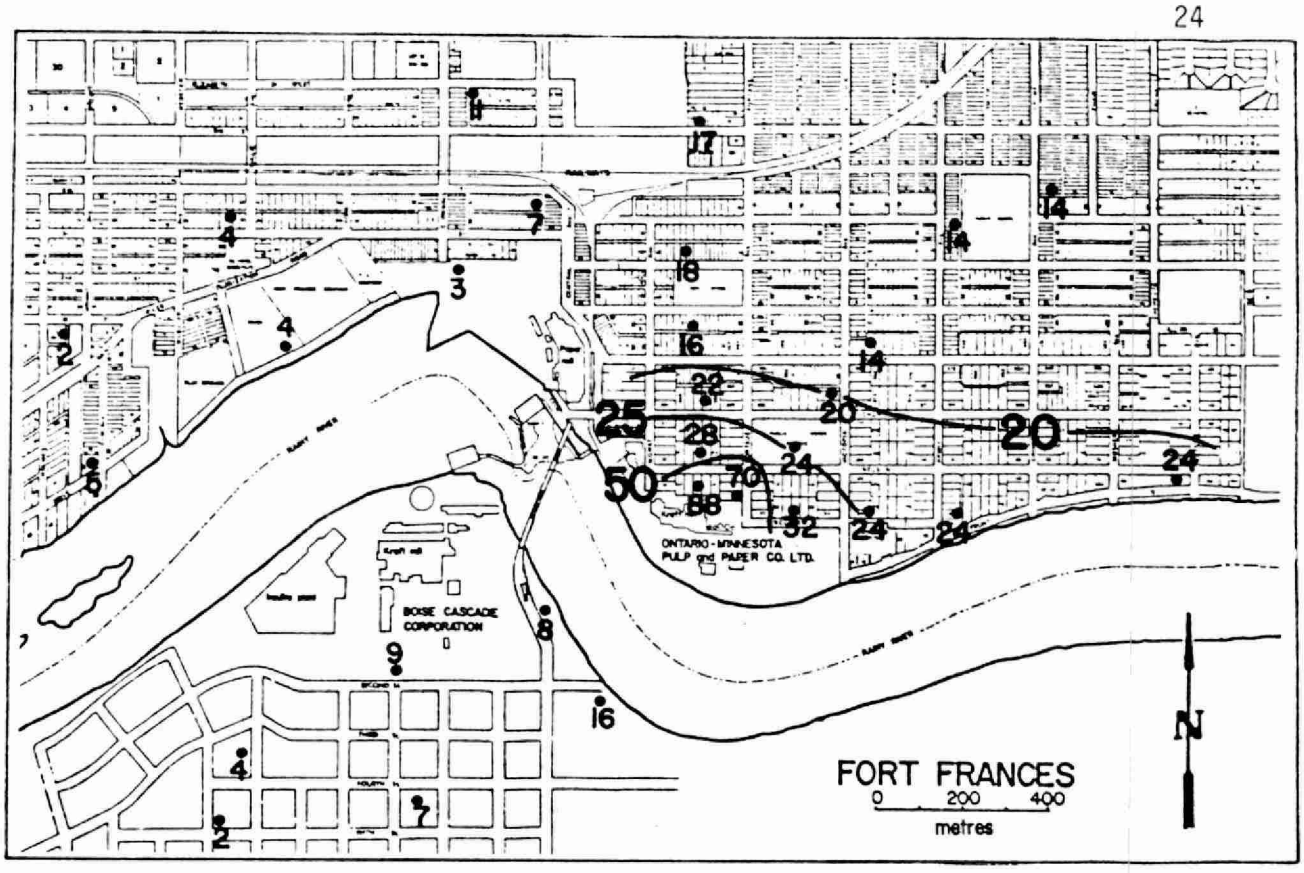

Figure 10a. Sodium levels (mg/l) in snow, February, 1977.

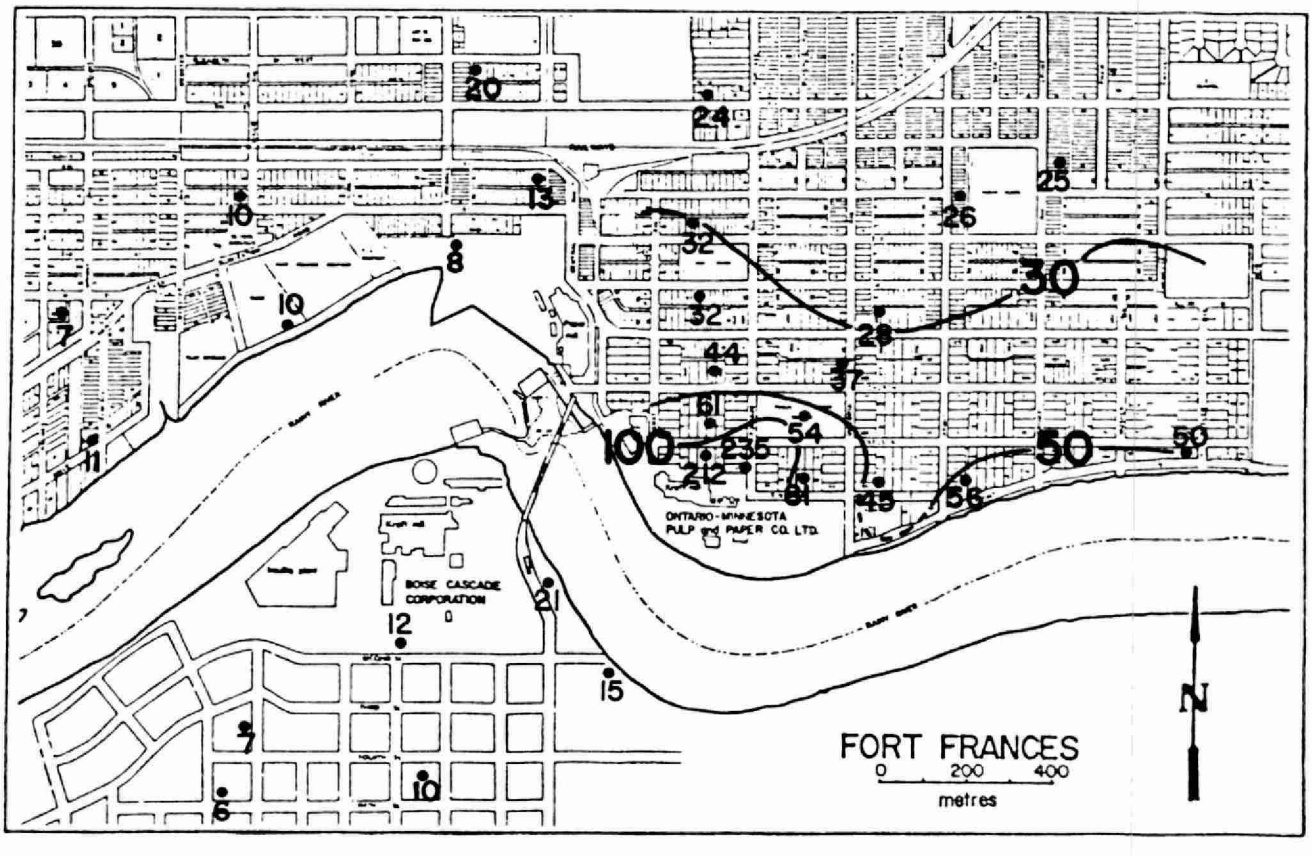

Figure 10b. Sulphate levels (mg/l) in snow, February, 1977.

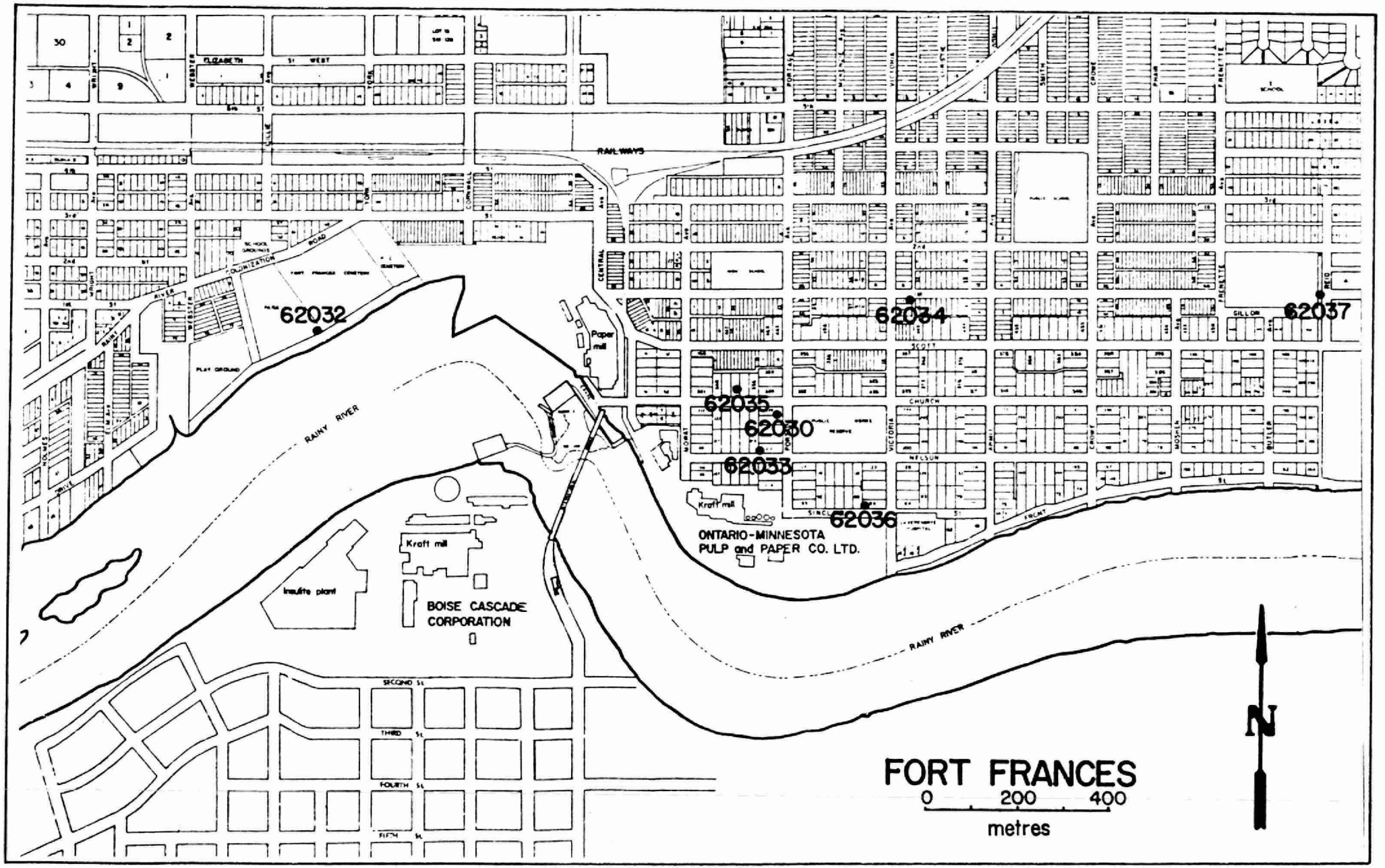

Figure II. Air quality monitoring sites, 1977.

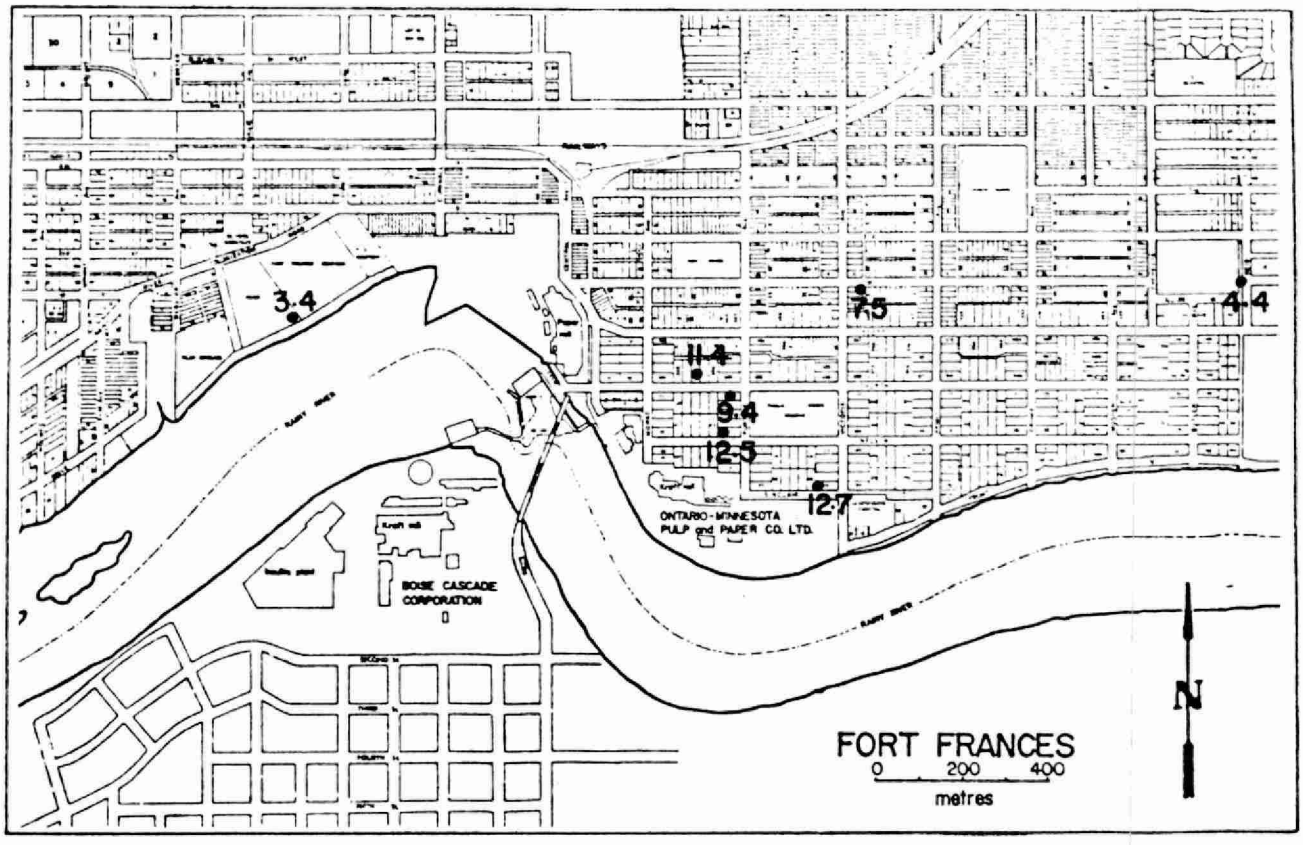

Figure 12a. Average dustfall, 1977 (g / m^2 / 30 days).

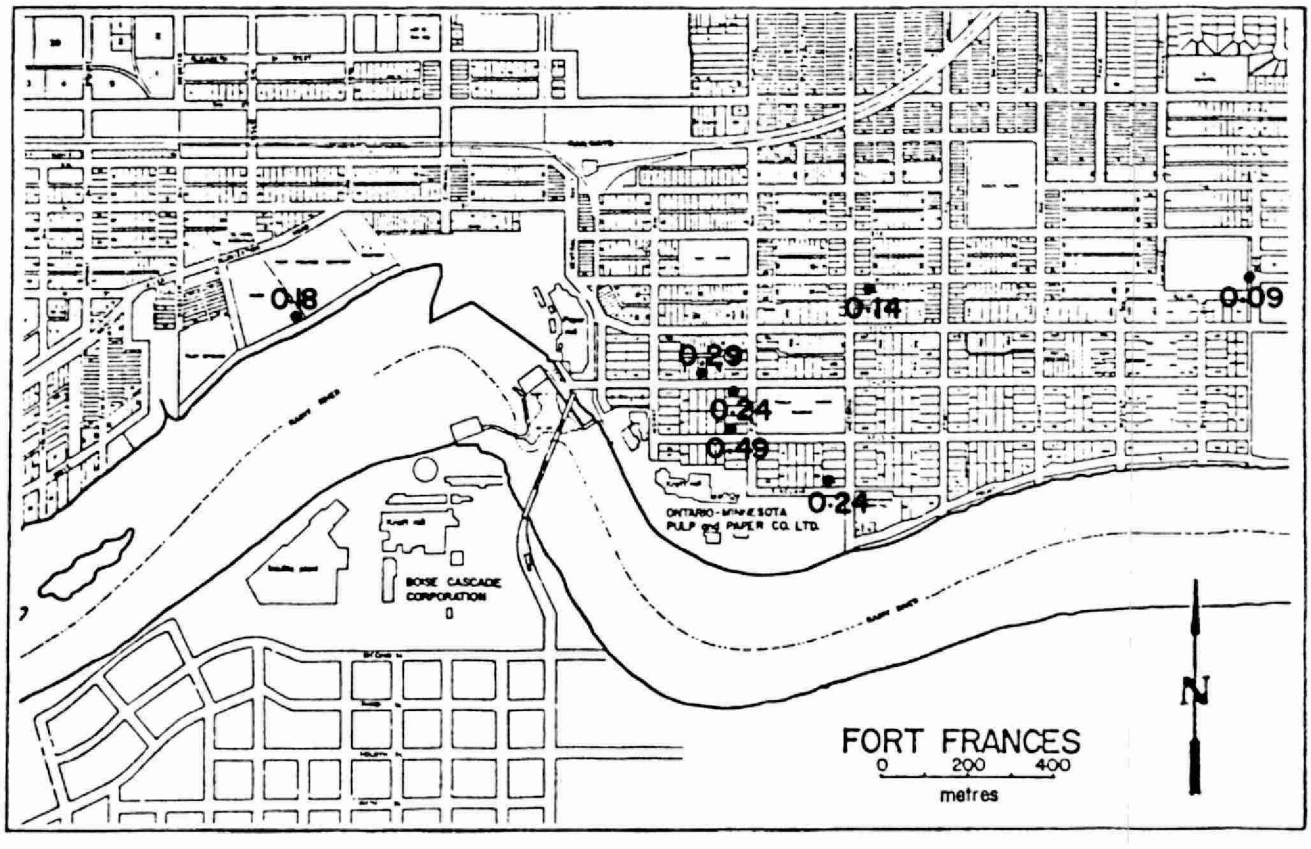

Figure 12b. Average sulphation rates, 1977 (mg SO_3 / 100 cm^2 / day).

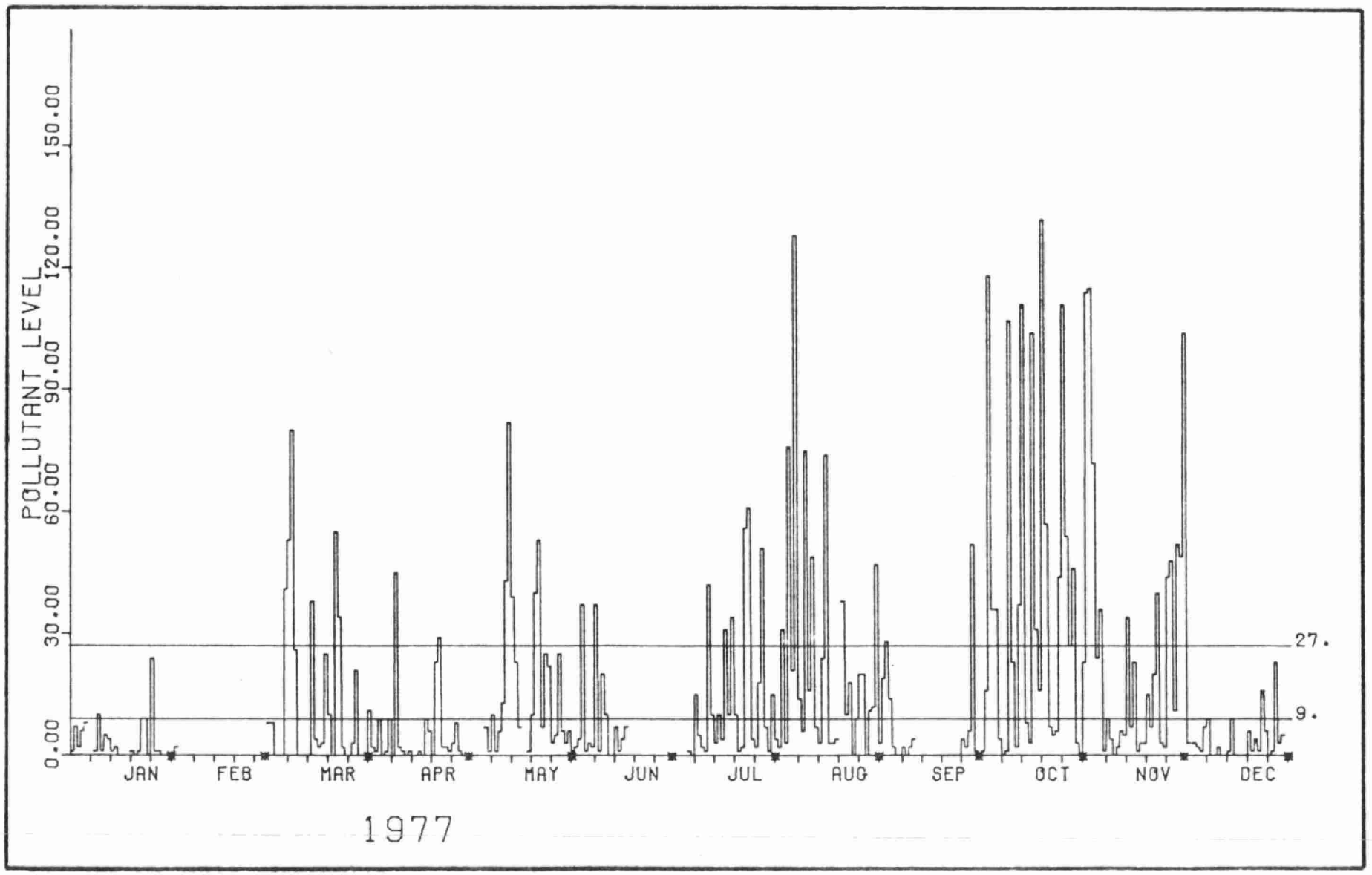

Figure 13. Daily mean TRS concentrations (parts per billion), station 62030, Fort Frances, 1977.

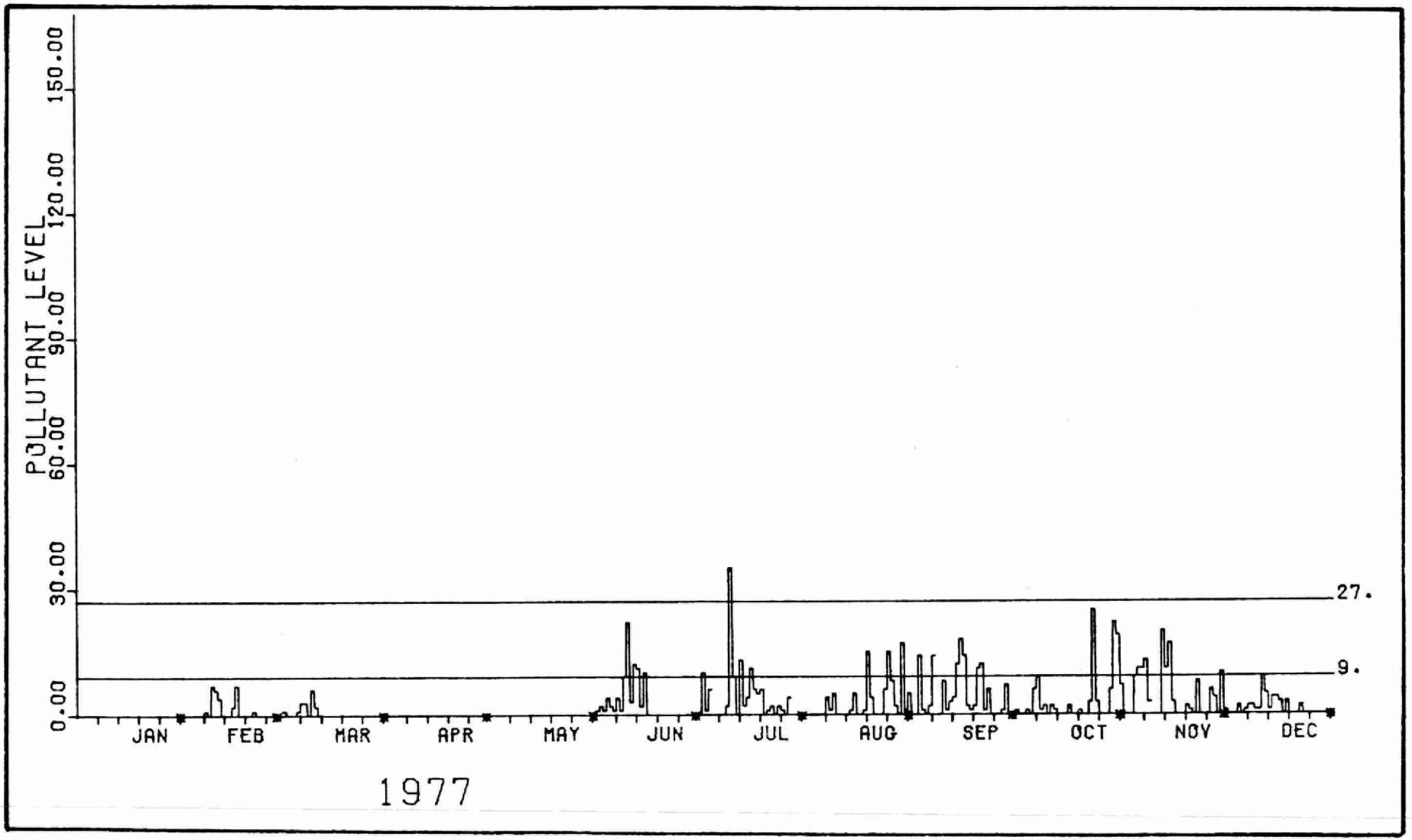

Figure 14. Daily mean TRS concentrations (parts per billion), station 62032, Fort Frances, 1977.

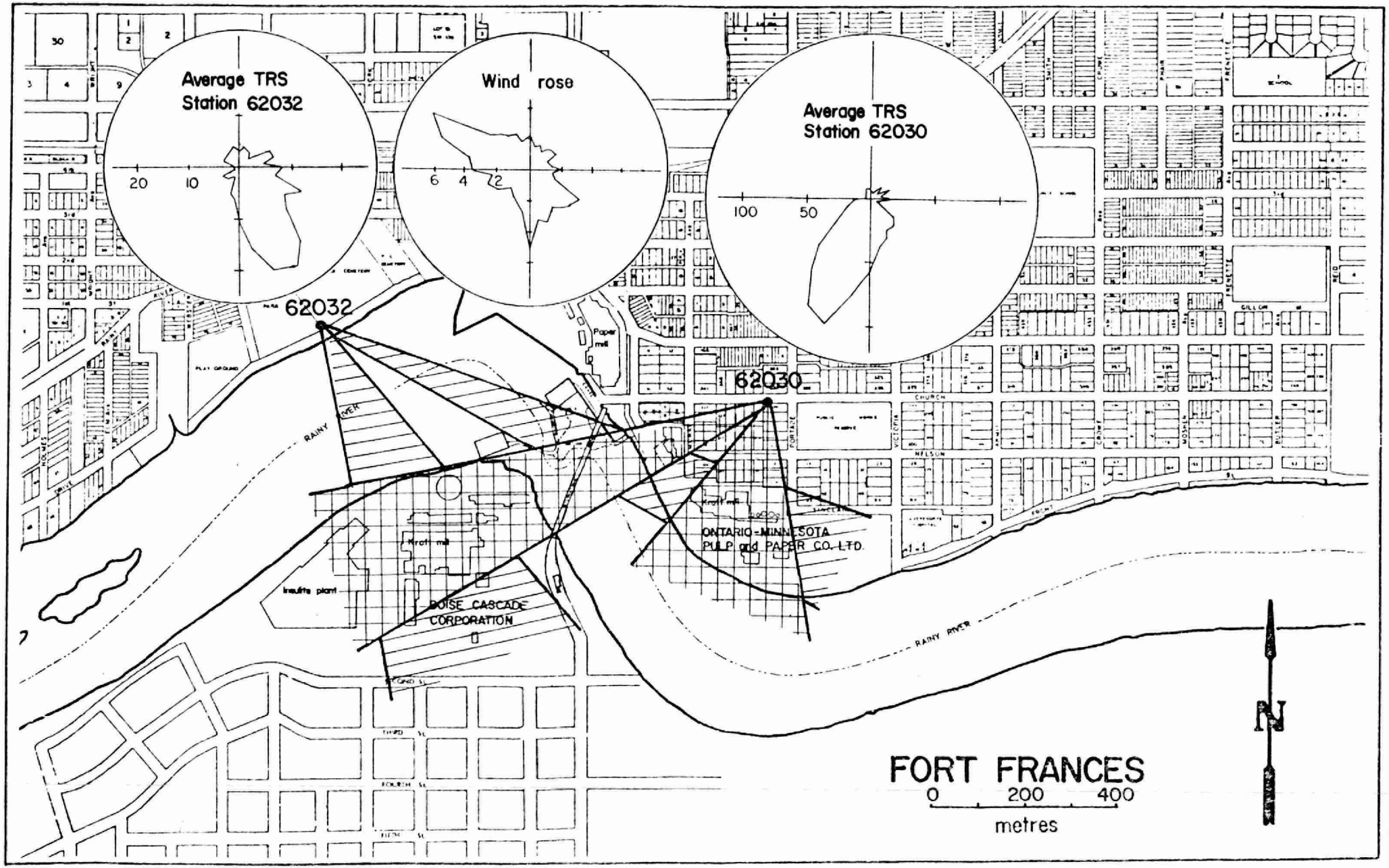

Figure 15. Wind rose (frequency percent) and pollution roses of average hourly TRS concentrations (ppb), 1977.

TABLE 1. Sodium and chloride content of not washed Manitoba maple foliage[a], Fort Frances-International Falls, 1974-1977.

Site	Sodium (µg/g, dry weight)				Chloride (%, dry weight)			
	1974	1975	1976	1977	1974	1975	1976	1977
1	890	540	770	2200	.32	.26	.29	.37
2	620	330	580	370	.18	.09	.14	.12
3		250	170	180		.07	.13	.06
4	520	220	120	240	.07	.06	.08	.04
5	450	200	120	130	.19	.18	.14	.09
6		180	140	230		.12	.11	.09
7	480	640	390	550	.26	.22	.15	.16
8	220	190	150	140	.15	.13	.12	.13
9	210	180	180	230	.10	.12	.16	.06
10		130	180	120		.08	.10	.10
11		310	930	160		.13	.12	.13
12		1500	1300	2300		.36	.16	.32
13	500	460	1100	600	.18	.37	.16	.18
14		400	120	140		.33	.14	.20
15	380	320	100	150	.16	.08	.09	.07
16		500	140	300		.15	.14	.12
17		370	180	320		.11	.13	.13
18	320	510	100	270	.07	.10	.13	.09
19		350	180	140		.08	.10	.12
20		310	120	250		.11	.11	.08
21		560	130	140		.07	.08	.06
22		720	160	370		.10	.10	.09
23	1800	1500	160	100	.04	.04	.03	.04
24		400	88	75		.04	.05	.05
25		360	77	98		.09	.12	.09
26		270	95	83		.10	.11	.09
27		1000	140	290		.13	.12	.05
28		310	220	160		.13	.17	.09
29		700	150	150		.05	.08	.06
30		180	97	230		.05	.07	.05
31		280	100	140		.10	.07	.04
32		170	97	94		.03	.06	.03
Control	88	50	43	47	.05	.04	.06	.04
Control	59	89	110	58	.05	.03	.04	.09

[a]1974 data represent averages of three sets of single samples, 1975 data represent averages of three sets of triplicate samples, and 1976 and 1977 data are averages of one set of triplicate samples.

TABLE 2. Sodium and chloride concentrations in Manitoba maple foliage facing and away from the Ontario-Minnesota kraft mill, August, 1977.

Site	Distance (metres) from source[a]	Sodium (µg/g)		Chloride (%)	
		Facing	Away	Facing	Away
12	75	2300	1400	0.32	0.34
13	145	600	310	0.18	0.24
14	270	140	130	0.20	0.20
15	400	150	180	0.07	0.07
16	600	300	130	0.12	0.11

[a]Source arbitrarily designated as recovery furnace stack, Ontario-Minnesota kraft mill.

TABLE 3. Comparison between levels of calcium, carbon, chloride, sodium and sulphate (all in mg/l) in snow collected in Fort Frances and International Falls, December, 1975, and February, 1977.

Distance (metres) and direction from source	Calcium		Carbon		Chloride		Sodium		Sulphate	
	1975	1977	1975	1977	1975	1977	1975	1977	1975	1977
50 N[a]	2	33	6	190	< 1	12	8	88	19	210
150 N	2	10	12	86	< 1	6	13	28	24	61
250 N	< 1	10	5	120	< 1	2	7	22	15	44
400 N	< 1	4	11	33	< 1	2	15	16	27	32
600 N	< 1	5	29	17	< 1	2	16	18	28	32
900 N	2	3	6	12	1	1	21	17	39	24
250 NE	2	10	4	125	< 1	2	10	24	22	54
400 NE	< 1	7	6	77	< 1	2	9	20	19	37
550 NE	< 1	6	4	35	1	1	8	14	16	28
850 NE	< 1	2	5	11	< 1	< 1	6	14	12	26
1100 NE	< 1	3	1	12	< 1	< 1	5	14	10	25
80 E	4	18	8	210	1	6	19	70	29	240
250 E	2	10	8	420	< 1	2	13	32	23	81
400 E	2	6	6	83	< 1	1	10	24	18	45
650 E	2	8	3	54	< 1	1	7	24	15	56
1050 E	2	5	1	25	< 1	3	6	24	12	50
500 NNE[b]	2	2	20	36	2	< 1	140	3	180	8
780 NNE	2	2	9	9	2	< 1	73	7	160	13
1000 NNE	< 1	2	9	9	1	< 1	55	11	110	20
400 ESE	6	14	25	100	2	4	74	8	150	21
625 ESE	2	12	14	62	2	19	51	16	90	15
280 SSE	2	4	21	72	4	8	76	9	150	12
500 S	2	4	30	50	1	7	40	7	72	10
425 SW	2	2	10	9	< 1	1	13	4	25	7
700 SW	2	1	6	7	1	< 1	22	2	40	6
700 WNW	-	1	8	17	-	< 1	-	5	-	11
900 WNW	2	2	3	19	1	1	19	2	35	7
500 NNW	2	1	5	14	< 1	< 1	20	4	36	10
750 NNW	< 1	< 1	3	-	< 1	< 1	12	4	22	10
Control east	2	1	< 1	6	< 1	< 1	< 1	2	5	6
Control west	< 1	< 1	< 1	6	1	2	< 1	< 1	1	2

[a]Locations of first 16 stations cited in relation to Ontario-Minnesota recovery furnace stack.

[b]Locations of remaining 13 stations cited in relation to Boise Cascade recovery furnace stack.

TABLE 4. Total dustfall and soluble sulphate in dustfall, Fort Frances, 1977.

Station	Location	Distance (metres) and direction from source[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
			Total dustfall (g/m^2/30 days)												
62030	Church/Portage	215 NNE	6.1	8.9[b]	16.1	12.1	16.4	10.7	8.9	9.4	5.8	6.1	3.3	-	9.4
62032	Cemetery	990 WNW	0.6	0.6	4.4	4.6	7.2	6.6	3.9	4.6	2.3	1.0	1.7	-	3.4
62033	Nelson/Portage	135 NNE	11.2	10.1	16.4	14.3	22.1	12.7	10.6	12.6	8.0	12.9	6.9	-	12.5
62034	First/Victoria	590 NE	3.6	1.3	9.4	9.9	14.0	12.7	6.7	8.7	-	6.7	2.3	-	7.5
62035	Legion Building	250 N	7.2	13.3	16.0	12.3	21.2	10.5	10.3	10.6	9.5	8.1	6.3	-	11.4
62036	Sinclair/Victoria	295 E	-	7.4	13.5	-	17.8	17.3	12.2	13.0	9.2	6.5	17.7	-	12.7
62037	Reid/Gillon	1385 ENE	4.7	1.9	-	6.1	12.6	3.9	2.4	3.9	-	0.5	3.8	-	4.4
			Soluble sulphate in dustfall (g/m^2/30 days)												
62030	Church/Portage	215 NNE	1.3	2.4	1.8	1.1	2.2	1.6	1.0	1.4	0.6	1.0	0.7	< 0.1	1.3
62032	Cemetery	990 WNW	0.2	0.4	1.0	0.6	1.4	1.2	0.3	0.5	0.4	0.2	0.2	0.1	0.5
62033	Nelson/Portage	135 NNE	3.5	5.6	3.6	1.5	5.6	3.4	3.0	3.7	1.8	3.9	2.3	0.8	3.2
62034	First/Victoria	590 NE	0.8	0.9	1.4	0.5	1.9	1.0	0.5	0.9	-	0.7	0.4	0.2	0.8
62035	Legion Building	250 N	1.5	4.8	1.8	1.2	2.5	1.6	1.4	1.6	1.2	1.4	1.5	0.3	1.7
62036	Sinclair/Victoria	295 E	-	2.0	1.5	0.6	1.3	1.4	1.1	2.1	1.0	0.6	4.1	1.2	1.5
62037	Reid/Gillon	1385 ENE	0.6	0.6	-	0.5	1.6	0.7	0.3	0.7	-	0.3	0.5	2.2	0.8

[a]Source arbitrarily designated as Ontario-Minnesota kraft mill recovery furnace stack.

[b]Values above air quality objectives of 7.0 (monthly) or 4.6 (annual average) are underlined.

TABLE 5. Total suspended particulate ($\mu g/m^3$), Fort Frances, 1977.

Date	Stations 62030	Stations 62032	Wind[a]	Date	Stations 62030	Stations 62032	Wind
Jan 1	12	17	300	Jul 6	57	58	330
7	28	20	270	12	71	40	290
13	49	37	140	18	-	-	-
19	39	26	210	24	62	-	330
25	113	11	250	30	60	-	170
31	25	16	290				
				Aug 5	67	30	270
Feb 6	51	14	310	11	86	37	260
12	43	14	310	17	42	35	310
18	173[b]	29	320	23	51	61	300
24	31	18	10	29	90	45	170
Mar 2	93	20	250	Sep 4	38	22	340
8	253	43	190	10	34	21	190
14	57	21	200	16	110	98	160
20	167	49	300	22	31	25	100
26	-	10	150	28	-	27	220
Apr 1	-	72	170	Oct 4	-	-	-
7	180	64	320	10	140	62	280
13	177	85	70	16	91	29	190
19	58	69	50	22	53	45	20
25	89	96	280	28	174	-	160
May 1	99	106	300	Nov 3	89	37	260
7	81	50	280	9	24	6	360
13	241	91	130	15	58	40	120
19	-	45	90	21	38	14	280
25	-	129	150	27	55	44	100
31	-	-	-				
				Dec 3	27	20	290
Jun 6	-	-	-	9	28	15	340
12	-	-	-	15	36	29	120
18	48	23	310	21	23	10	300
24	82	71	300	27	90	18	210
30	50	31	240				

[a]Prevailing wind direction, degrees, recorded 6.4 m above ground level at International Falls airport.

[b]Values above air quality objective of 120 $\mu g/m^3$ (24-hour average) are underlined.

TABLE 6. Sulphation rates (mg SO_3/100 cm^2/day), Fort Frances, 1977.

Station	Location	Distance (metres) and direction from source[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
62030	Church/Portage	215 NNE	.16	.20	.19	.13	.15	.20	.30	.25	.21	.69	.34	.12	.24
62032	Cemetery	990 WNW	< .03	.10	.11	.13	.13	.20	.30	.13	.10	.35	.30	.23	.18
62033	Nelson/Portage	135 NNE	.26	.44	.36	.21	.25	.44	.55	.90	.50	1.27	.58	.16	.49
62034	First/Victoria	590 NE	.08	.14	.18	.15	.15	.10	.17	.04	.12	.19	.17	.18	.14
62035	Legion Building	250 N	.15	.20	.27	.19	.20	-	.37	.39	.33	.51	.38	.17	.29
62036	Sinclair/Victoria	295 E	-	.20	.26	.11	.15	.13	.39	.34	.26	.24	.40	.15	.24
62037	Reid/Gillon	1385 ENE	.06	.03	-	.03	.06	.06	.17	.07	.18	.06	.17	.10	.09

[a]Source arbitrarily designated as Ontario-Minnesota kraft mill recovery furnace stack.

TABLE 7. Distribution of total reduced sulphur readings (ppb, hourly averages) in Fort Frances, 1977.

Month	Days of data	Number of readings for concentrations of: 0-10	11-27	28-50	51-100	101-500	>500	Maximum value Hourly	Daily
				Station 62030					
Jan	27	629	38	11	13	0	0	91	24
Feb	1	37	1	3	0	0	0	43	2
Mar	31	548	89	38	29	29	0	295	80
Apr	28	593	25	17	13	8	0	269	45
May	25	431	66	46	43	25	0	255	82
Jun	16	331	24	13	14	8	0	236	37
Jul	27	485	58	37	40	25	0	262	61
Aug	30	486	94	44	48	56	0	476	128
Sep	20	415	29	10	18	9	0	169	52
Oct	31	376	78	52	51	92	0	480	132
Nov	30	439	85	36	53	66	0	309	115
Dec	28	604	45	17	7	0	0	92	23
Year	294	5374	632	324	329	318	0	480	132
				Station 62032					
Jan				no data					
Feb	24	584	15	4	1	1	0	129	7
Mar	11	323	5	0	0	0	0	23	6
Apr				no data					
May				no data					
Jun	16	309	43	14	4	0	0	63	22
Jul	25	480	48	27	8	0	0	59	35
Aug	29	580	34	19	5	0	0	99	17
Sep	29	556	51	25	9	0	0	77	18
Oct	31	608	48	22	4	0	0	69	25
Nov	29	547	68	26	5	0	0	86	0
Dec	31	639	14	2	0	0	0	45	9
Year	225	4626	326	139	36	1	0	129	35

TABLE 8. Directional distribution of hourly average readings of total reduced sulphur (TRS) at stations 62030 and 62032, Fort Frances, 1977.

Wind direction[a]	Number of hours when TRS was monitored		Average concentration (ppb) when TRS was monitored	
	62030	62032	62030	62032
10	8	29	3	4
20	10	28	6	4
30	1	15	5	3
40	6	12	13	4
50	4	12	4	2
60	9	14	18	7
70	4	16	6	7
80	6	15	11	4
90	8	22	16	8
100	6	38	7	7
110	9	49	3	13
120	26	157	6	10
130	36	127	22	12
140	43	103	24	18
150	48	104	27	22
160	110	149	32	21
170	121	108	39	16
180	287	131	56	10
190	178	50	76	6
200	144	22	105	5
210	131	9	91	2
220	114	11	70	3
230	100	2	52	2
240	159	5	27	4
250	167	5	21	1
260	150	11	15	2
270	171	4	11	1
280	119	7	6	1
290	162	9	6	3
300	135	11	6	2
310	74	12	5	2
320	64	7	8	3
330	70	13	9	3
340	58	28	9	2
350	24	32	10	4
360	15	33	4	3
Calm	340	113	26	8

[a]Degrees, recorded 6.4 m above ground at International Falls airport.

Date Due
